DOCUMENT RESUME

ED 151 750 CS 003 981

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TITLE Organization of Cognitive Functions in the Brain.
PUB DATE Nov 76
NOTE 9p.; Paper presented at the Annual Meeting of the Orton Society, Inc. (27th, New York City, November 2-6, 1976)

EDRS PRICE MF-$0.83 HC-$1.67 Plus Postage.
DESCRIPTORS Adult Characteristics; *Cerebral Dominance; Child Development; *Cognitive Development; *Cognitive Processes; Handicap Detection; Human Development; *Language Ability; Learning Disabilities; *Nonverbal Ability; Reading Difficulty; Surgery; *Verbal Ability

ABSTRACT

Neuropsychological research on the effects of hemispherectomy-the excision of one of the cerebral hemispheres-in children and adults adds to knowledge about the division of labor between the left cerebral hemisphere, which specializes in language and verbal cognitive functions, and the right hemisphere, which specializes in nonlanguage functions. Comparisons of effects of left hemispherectomy in 28 infants and of right hemispherectomy in 17 infants revealed no systematic differences in language or nonlanguage functions or in their subsequent development. Findings for adult hemispherectomy patients showed that there is significantly greater recovery of language functions after left hemispherectomy than of nonlanguage functions after right hemispherectomy. The findings suggest that the biological substrata for language and nonlanguage cognitive functions are duplicated and present in each hemisphere at birth, and that the plasticity of language functions in early life, though diminishing with age and verbal maturation, is present in adulthood. Findings relating to hemispheric functions may have applications for early detection of children with reading and other learning disabilities. (GW)

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ORGANIZATION OF COGNITIVE FUNCTIONS IN THE BRAIN

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Beginning with studies of long term effects of the surgically designed bilateral lesions in lobotomy, topectomy and other "psychosurgical" procedures in 1955, I have been engaged in numerous studies of initial and later effects of the various types of brain insults including vascular, neoplastic, traumatic, and other cerebral lesions on "higher" (cognitive) versus "lower" (sensory and motor) mechanisms in children and adults. The aim of these studies was to systematically accumulate data reflecting the principles underlying the organization and development of cerebral functions; the various patterns of disorganization resulting from lesions incurred at different stages in the maturation of the normal brain from birth to late adulthood; and the principles underlying the different patterns of reorganization of cerebral functions following brain insults at different stages in the maturation of the brain.

As you know, the diverse current concepts of the organization of "cognitive" functions and differences in the roles of the left and right cerebral hemispheres and other neural structures in language and nonlanguage functions have been largely based on studies of children and adults with focal lateralized cerebral lesions. Thanks to the persisting efforts of Dr. Joseph Bogen, more recently, numerous studies of a relatively small number of children and adults with commissurotomy for lateralized or bilateral epileptogenic lesions have added relatively unique data and conclusions to the historical controversies on the division of hemispheric labors in the higher "cognitive" and lower "sensory and motor" level functions in language and nonlanguage functions. To what extent are the various higher "cognitive" functions and the lower level "sensory and motor" functions involved in speech, verbal comprehension, reading, writing, verbal reasoning and memory exclusively or predominantly "localized" in circumscribed mechanisms within the left hemisphere? And to what extent are other nonlanguage cognitive functions such as visual ideational, perceptual, spatial-constructional and visual memory functions similarly "localized" in circumscribed areas or centers of the right hemisphere?

We all know that differences between the roles of the two cerebral hemispheres in language and nonlanguage functions were described by Jackson (1873, 1876). He rejected the popular claims of the localization of specific language functions in circumscribed areas of the left hemisphere. However, based on his brilliant clinical observations he also reported specific nonlanguage mental defects unique to posterior lesions in the right hemisphere. Thus, he described the left as the "leading" rather than exclusive hemisphere in mediating language functions, and the right as the "leading" hemisphere in visual ideational or nonlanguage mental functions.

Jackson's views were largely ignored until Paterson and Zangwill (1944, 1945) confirmed his findings in studies of adults with lateralized brain lesions. Please notice that I specified adults since, as ours and other studies of children have demonstrated, the organization and development of cognitive language and nonlanguage functions following lateralized brain lesions in children differ markedly from those in the adult.

Indeed, since the findings in comparisons of effects of lateralized brain insults in children and adults have conceivably important practical as well as

Presented at the 27th Annual Conference of The Orton Society, Inc. November, 1976, New York City

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theoretical implications, the primary focus of this presentation will be on comparisons of the findings in our neuropsychological studies of initial and later effects of hemispherectomy -- the excision of either the right or left hemisphere -- in children (usually for pre- peri- or early post-natal brain insults resulting in intractable seizures) and in adults whose two cerebral hemispheres had developed normally until one was excised, usually because of the development of a malignant and otherwise inevitably fatal brain tumor.

Before considering comparisons of initial and later effects of hemispherectomy for epileptogenic lesions incurred in early infancy in 27 cases with left and 18 with right hemispherectomy; and in five adults with right and two with left dominant hemispherectomy for lesions (six with tumors, one war missile wound) incurred in adulthood, some selected current and earlier related findings may provide a context for evaluating our findings and their possible implications with respect to the development of normal reading, language and nonlanguage functions.

Although not necessarily representative, let us consider some of the recent conclusions of a few well known authors, including those of the well-known speaker, Prof. Gazzaniga whom you have just heard.

1. H.W. Magoun wrote, "Man's capacities for communicating by symbolic language are also unique in depending upon neural mechanisms which develop only in the dominant one of the two cerebral hemispheres rather than bilaterally." (When I wrote Dr. Magoun for evidence supporting this view, I believe he replied that he thought this was a well-established finding). (1967, p.18).
2. Howes: "I hate to see us give up too soon the notion that language is in fact unilaterally organized....It makes sense to think of language as having to be integrated in one physical location, at least in the adult. Certainly over 90 percent of adult cases are clearly unilateral, either on one side or the other" (1964, p.217).
3. Money. "The word is a single unit, not a bilateral one. The brain does not represent it in two places, but in one hemisphere" (1969, p.380).
4. Lenneberg. "In the absence of pathology, a polarization of function between right and left (hemispheres) takes place, displacing language entirely to the left and certain other functions entirely to the right" (1967, p.153).

Based on studies of patients with commissurotomy, Sperry and Gazzaniga wrote, "....the minor hemisphere is unable to talk or write....it is silent, mute, speechless" (1967, p.111-112), and Gazzaniga and Hillyard reported, "Indeed, more operational language competence has been shown for the chimp than has been demonstrated in the human right hemisphere" (1971, p.279-280). (Those of you familiar with the recent literature on commissurotomy may note that the neurosurgeon who developed the recent collaborative studies of the so-called "split brain" patients, Dr. Joseph Bogen, has not subscribed to these conclusions. Since he had an opportunity to observe the 47 year old adult after left dominant hemispherectomy for tumor reported by Dr. Burklund and myself in 1967, perhaps this is not surprising).

These conclusions, however, are based on studies of clinical populations with heterogenous and variously situated and circumscribed cerebral lesions. Thus, as Dandy (1933) and others (Smith, 1962,1969,1972,1975; Smith and Sugar, 1975) have suggested, the continuing controversial findings on initial and later effects of diverse brain insults in children and adults by other investigators reflect the inherent ambiguities in such studies.

The development of hemispherectomy for glioma by Dandy (1928) and for intractable seizures in infantile hemiplegics by Krynauw (1950) permitted comparisons of initial and later effects of removing a hemisphere that had been damaged in early infancy with those resulting from removing a hemisphere that had matured normally until growth of a neoplasm in adulthood. Consistent with Jackson's descriptions of quantitative rather than qualitative differences in the functions of the two hemispheres, comparisons of right hemispherectomy in five (four for tumor; one missile wound) and of left hemispherectomy for tumor in two adults revealed marked and systematic differences in initial and later effects on language, verbal and nonverbal cognitive functions, and visual and auditory memory.

In five dextrals 24 to 66 years old when tested after right hemispherectomy, language, verbal reasoning and memory were relatively intact but visual ideational, memory and spatial-constructional functions were severely impaired. The mean WAIS Verbal IQ (100.6) and Peabody Picture Vocabulary (115) were in the normal range. However, the mean WAIS Performance IQ (70.6), Hooper Visual Organization (15.6), Raven Coloured Matrices (15.2) and Benton Visual Retention (2) were markedly subnormal. Follow-up studies of two of these five patients and single examinations at one month, 15 and 30 years postoperatively indicated no improvement in the severe impairment in nonverbal cognitive functions. The persisting severe impairment in nonverbal cognitive functions 15 and 30 years postoperatively thus suggests marked limitations in the capacities of the left hemisphere and other residual neural structures to compensate for the nonlanguage defects following removal of a normally matured right hemisphere.

Left dominant hemispherectomy for tumor in adults is rare. The first case reported by Zollinger (1935) revealed that although severely impaired, speech and verbal comprehension were present immediately after surgery. While the patient died 17 days postoperatively, since expressive and receptive language functions continued to improve in the short survival period, Zollinger expressed the belief that with continuing survival, language functions might have continued to improve, possibly approaching normal levels. Basser (1962) reported short survivals in six adults with left hemispherectomy. However, in addition to noting that comprehension was relatively spared in all cases, speech was present in five after operation and showed continuing improvement until death.

The only available evidence of the capacities of the right hemisphere and other residual neural structures to continue to compensate for the impairment in language, verbal cognitive and auditory memory functions consists of two dextrals, 47 and 41 years old who survived for 24 and 18 months respectively until death due to recurrence of the tumor. However, in contrast to the persisting severe impairment in nonverbal functions after right hemispherectomy and descriptions of the right hemisphere as "silent, mute, speechless," although severely impaired, speech was present shortly after surgery, and both patients showed continuing improvement in speech, verbal comprehension, reading and writing until overt signs of the recurrence of the tumor at 13 and 9 months postoperatively. In both patients, verbal comprehension was initially least impaired and showed faster and greater recovery than speech, reading or writing. Tests of nonverbal functions also showed recovery of normal preoperative levels before recurrence of the tumor. The continuing recovery of language functions after left hemispherectomy in these two adults, and the persisting severe impairment in nonlanguage functions in four of the five adults with survival periods of from 4 to 30 years (one is still living) after right hemispherectomy, suggest that the capacity of the residual structures to compensate for the loss of language and verbal cognitive functions after left hemispherectomy in adults is greater than that of similar residual structures to compensate for the loss of nonverbal cognitive functions after right hemispherectomy. The continuing improvement or greater plasticity of language than

nonlanguage functions following the massive insult of left hemispherectomy in the normally matured adult brain, is also consistent with earlier findings reported by Bastian (1898) attributing such improvement to the compensating role of the right hemisphere. Based on studies of initial and later effects of aphasiogenic lesions, Bastian reported that the functional plasticity is greatest in children, and although diminishing with age, continues long beyond middle age.

While the plasticity of language and other hemispheric functions in children and adults was reported by Broca (1865), Bastian (1898) and others, based on studies of hemiplegic and nonhemiplegic children with cerebral lesions at or shortly after birth, Teuber wrote that earlier reports of "the plasticity of the nervous system may have been overrated" (1970, p.16). Citing similar findings in selected studies, Teuber and his colleagues reported that comparisons of children with prenatal or perinatal lesions "....strongly suggest that the adult pattern of reciprocal specialization of the hemispheres may indeed exist before birth, since the brain injured children showed a reciprocal pattern of symptoms, depending on whether the right or left side of the body was predominantly involved" (Rudel, Teuber and Twitchell, 1974, p.105). Later, noting that these results apparently contradict the findings in hemispherectomy in children, Teuber reported that when language develops in the right hemisphere of children with left hemisphere lesions, it does so at the expense of the development of nonlanguage functions. Teuber reported that when patients with left hemisphere lesions in early infancy are tested in their teens and early twenties, they "show some language retardation and marked deficits in visuospatial tasks" reflecting "consequent crowding when one hemisphere tries to do more than it was originally meant to do" (Teuber, 1974, p.73).

In light of these conclusions by such eminent authors, let me pose a question. Suppose there was an infant who showed cyanotic difficulties at birth at term by cesarean section. Right hemiparesis is noted at five months of age. Jacksonian right-sided seizures begin at the age of 3 years and 10 months and, despite anticonvulsant medication, increase to 10 to 12 per day at the age of 5 1/2 years. Speech had deteriorated until it was practically unintelligible, with corresponding deterioration of mental and motor functions as the seizures increased in frequency. Recognizing that such persisting seizures often result in irreversible mental retardation, a neurosurgeon decides to remove the entire left cerebral hemisphere.

Now, how many of you believe that in such a case, if the seizures were eliminated by excision of the left hemisphere, speech and language functions might develop normally? (Hands)

How many believe that speech might eventually become normal but that other language functions like reading and writing, verbal reasoning and verbal memory would show limited or subnormal development? (Hands)

And how many think that if this patient were to grow to maturity, intelligence would be normal? (Hands)

Could such a patient ever go to college?

Well, there is such a patient who was operated upon by Dr. Oscar Sugar in Chicago on July 28, 1953. I first examined him in 1969 (15 1/2 years postoperatively) and at the ages of 26 1/2 and 27 1/2 years. On reexamination in 1974, he was working successfully as an industrial executive (traffic controller). He was also then completing his senior year at a prominent midwestern university. His 1975 tests revealed a WAIS Verbal IQ of 126 and Peabody Picture Vocabulary score of 141+/IQ 139+, no ceiling obtained, both in the superior range. His WAIS Performance IQ (106) was in the normal range but his Standard Progressive Matrices, a test of nonverbal visual analogous reasoning, showed a score of 50, which is above the 80th percentile. (Results of the first two examinations 15 1/2 and 21 years postoperatively have been reported (Smith and Sugar, 1975).

Although this is an exceptional case among 27 with left and 18 with right hemispherectomy, the development of superior adult verbal and nonverbal cognitive or intellectual capacities indicates the presence of the necessary substrata for such capacities in the right hemisphere and for other intact residual neural structures after left hemispherectomy for perinatal epileptogenic lesions. Although time precludes detailed presentations of the findings, in contrast to Teuber's claims, comparisons of effects of left hemispherectomy in 28 patients and of right hemispherectomy in 17 patients for infantile epileptogenic lesions showed no systematic differences in language or nonlanguage functions or in their subsequent development as a function of the hemisphere removed.

The consistent findings of subsequent development or improvement of language functions after left or right hemispherectomy for epileptogenic lesions in this and almost all reported similar studies suggest that in the drastically reduced neuroanatomical economy resulting from extensive early brain damage and/or hemispherectomy, there is a developmental hierarchy in which the development of speech and verbal comprehension takes precedence over reading and writing, and over verbal and nonverbal cognitive functions. Since McIntire, Wiley and Wolski (1966) reported attenuated development of language functions associated with development of normal nonverbal cognitive functions in children, there are obvious exceptions to this pattern, apparently depending upon the nature and locus of early brain insults and other factors. However, the suggested priority and independence of speech and verbal comprehension in the development of cerebral functions was indicated by two of the 28 patients with left and two of the 17 patients with right hemispherectomy whose verbal and nonverbal reasoning capacities were below the lowest limits of standardized intelligence tests. In addition to similar cases reported in earlier similar studies, priorities for selective development of functional speech and verbal comprehension (but notably, not of reading or writing) are also evident in severely mentally retarded children. Thus, the findings indicate that the acquisition - or the development, organization and integration of the complex grammatic processes involved in speaking and understanding speech are, as Chomsky put it, "no more learned than, say, ability to walk is learned" (Chomsky, 1967, p.81). Thus, studies of hemispherectomy for early epileptogenic lesions indicate that the biological substrata for language and nonlanguage cognitive functions are duplicated and present in each hemisphere at birth.

The marked differences between effects of right or left hemispherectomy for early epileptogenic lesions and right or left hemispherectomy for tumor reflect the process of increasing "encephalization" of functions in the maturing brain. Long term follow-up studies of hemispherectomy for early epileptogenic lesions indicate that the biological substrata for language and nonlanguage cognitive functions are duplicated in each hemisphere at birth, and that the residual neural structures after left or right hemispherectomy for perinatal lesions will suffice for the development of normal or above normal capacities in such functions.

In adults with lesions incurred after the two cerebral hemispheres have developed normally, the reciprocal syndrome of selective impairment in nonlanguage functions and sparing of language and verbal cognitive functions after right hemispherectomy versus the severe impairment in language functions and sparing of nonlanguage functions after left hemispherectomy reflect the increasing functional specialization of the two cerebral hemispheres, the left hemisphere in language and verbal cognitive functions and the right in nonlanguage functions. However, the greater recovery of language functions after left hemispherectomy than of nonlanguage functions after right hemispherectomy indicates that the greater plasticity of language functions in early life, although diminishing with age and cerebral maturation, is present in adulthood. No cases with long term survival after left hemispherectomy for tumor have yet been reported. Thus, we do not know the maximum extent to which the various language functions might recover or the

ultimate language competence of the residual neural structures after excision of the adult left hemisphere. Nonetheless, the consistent findings of continuing improvement in language functions in our two adults with left hemispherectomy and in five other previously reported cases during shorter periods of postoperative survival clearly contradict earlier claims that speech or any of the language functions are "localized" exclusively in areas within the left hemisphere.

The conclusions of Professors Gazzaniga and Doty, including the claim that the specific memory patterns or engrams for speech are laid down only in the left hemisphere, are consistent with the 19th century "classical" view of the localization of speech exclusively in the adult left cerebral hemisphere. However, in contrast to the claims of Professors Gazzaniga and Doty, Butler and Norsell (1968) have reported right hemisphere speech in the patient with commissurotomy.

The capacity of the right hemisphere for speech, as well as for verbal comprehension, reading and writing, however, has been consistently demonstrated in the last two reported cases of left dominant hemispherectomy for tumor in adults by Dr. Burklund and myself (Smith and Burklund, 1966; Smith, 1966, 1972; Burklund, 1972; Burklund and Smith, in press). And as noted above, in five of six earlier reported similar cases with shorter periods of postoperative survival, Basser (1962) also reported speech was present after left hemispherectomy and continued to improve until death.

Apart from their theoretical implications, however, the evidence of the organization of different mechanisms in the left hemisphere specializing in language and verbal processes and of other mechanisms in the right hemisphere specializing in visual ideational nonverbal processes may have conceivably important practical applications for early detection of children with reading and other learning disabilities.

We have recently developed the Symbol Digit Modalities Test (Smith, 1973) which involves perceptual matching of nonverbal geometric figures (in which the right hemisphere specializes) and substitution of a number or verbal symbol in either speech or writing (in which the left hemisphere specializes). In an effort to identify children who would subsequently have difficulties in learning to read normally, Hutton (1973) administered the oral form of the Symbol Digit Modalities Test to 497 children at the completion of kindergarten. Their mean age was 80 months, and the test consisted of recording the number of spoken substitutions in a 90 second interval. One year later, after completion of the first grade when their mean age was 92 months, she administered the (British) Neale Reading test. Based on analyses of her data, she reported a cut-off score that she could identify with an accuracy of 80% those children who would have significant difficulties in learning to read.

She reported these findings in two independent studies of 157 and of 339 European children in kindergarten in the school system of Clarement, Cape Town, South Africa. Although the reliability of Hutton's findings has not yet been tested by similar studies of American children, it is interesting to note that the perceptual and symbolic processes involved in symbol-digit substitutions are strikingly similar to those involved in the acquisition of reading.

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